Assessing the Operating Reliability of Land Grid Array Elastomer Sockets

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***Abstract*—The contact resistances of 2300 elastomer button contacts used for LGA (land grid array) package interconnections were measured over a range of contact loads. The experimental data, fitted using three probability distribution functions, show that an inverse Gaussian distribution best describes elastomer button contact resistance behavior. Using this probability function, the minimum operating contact load necessary for a desired socket operating reliability can be determined.**

***Index Terms*—Automatic contact resistance measurement, conductive elastomer, contact resistance, elastomer button, electrical resistance distribution, land grid array (LGA), LGA elastomer socket.**

I. Introduction

THE component socket is a separable interconnect between electronic components and a printed circuit board (PCB). Component sockets are used in testing and burn-in applications and in component assembly. In both operations, the ability to easily remove and replace the component provides a distinct advantage over direct soldering. Upgrades and replacements can be attached quicker and with less cost and less damage because no heat is required to mount or separate the component from its substrate.

Socket connection also provides an advantage over soldered joints with regards to mechanical robustness/durability. Different materials in components and PCB's will expand and contract at different rates during the heating and cooling that occurs in the power-up and power-down stages of normal electrical operation, as well as under changing environmental conditions. This expansion mismatch can introduce stress concentrations in permanent interconnects, such as solder joints, which can lead to crack initiation and eventual electrical failure. The separable nature of sockets allows for sliding of the contact surfaces while still maintaining a good electrical connection. This compliant design greatly reduces damage due to fatigue or creep and can thus improve product reliability.

The use of elastomer buttons as contacts in component sockets is potentially a very powerful technology. Because an ability to produce a very fine pitch array, elastomeric contacts can yield higher density interconnection then the traditional spring contact socket technology. This increase in inputs/outputs (I/O's) can lead to greater integration on the silicon chip, reducing the size and number of components necessary for operation and leading to improvements in performance and reliability.

Improvement in performance through the use of elastomer component sockets does not reduce customer expectations of a highly dependable system. As with other surface mount connection technologies, the operating reliability of each individual contact becomes critical to the proper functioning of the entire socket.

Determining the contact resistance distribution plays a vital role in assessing the operating reliability of the device. Previous research has shown that electrical resistance behavior can be fitted to certain distribution functions [1]–[5]. Hamamoto *et al.* [1] found that the contact resistance distribution of semiconductor components used in integrated circuits display Gaussian behavior. Yu *et al.* [2] studied the resistance distribution for conductance fluctuations and found that the behavior was well characterized by either an inverse Gaussian or a log-normal distribution.

In this paper, the contact resistance behavior of elastomeric component sockets was fitted to three distribution functions. Using a best-fit approach, the results of this study provide a methodology for determining a minimum operating contact load based upon application requirements. The use of load as an influencing factor in elastomer button resistance behavior provides two pieces of critical information. It allows for high confidence product based upon a pass/fail specification. In addition, it provides information on the probability of high resistances that may lead to a loss of functionality, absent an actual failure.

II. Theory

The output of a measurement is often considered a statistical variable. Consider measuring the length of an object. In a perfect world, this value would be unique and repeatable. However, due to defects in the equipment, errors in measurement techniques, and small variations in temperature, the measurement readings oscillate around a real value and comply with a certain distribution. The distribution is stochastic in nature and therefore, the mean of this distribution is considered to be the length of the object.

When measuring multiple samples, errors introduced during measurement may not always be the dominant error. In the case of electrical connectors, fluctuations in measured resistance

Manuscript received March 15, 1999; revised November 6, 1999. This paper was recommended for publication by Associate Editor J. W. McBride upon evaluation of the reviewers' comments.

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Publisher Item Identifier S 1521-3331(00)02257-1.

may be due to variabilities in the materials, manufacturing process, and the localized environment; measurement variations may have a negligible effect. In other words, under proper testing conditions, resistance measurements of an electrical connector or contact should be accurate enough to be used as the real resistance value.

In this paper, initial experimentation was conducted to independently assess fluctuations in contact resistance due to environment and measurement techniques. This information was used to isolate contact resistance behavior due strictly to intrinsic variabilities. The electrical resistance of different contacts was then taken as a statistical variable and was described using probability density functions.

A. Distribution of Electric Bulk/Contact Resistance

Distribution functions are useful in predicting outlying behavior using a limited amount of experimental data. The normal distribution is a standard distribution that can approximate many natural phenomena. Electrical resistance does not generally comply with normal distributions because it is always greater than zero. This results in asymmetry about the mean since measurement variables become defined over the range $0 < R < -\infty$. However, if the skew is small, contact resistance behavior can be profiled as a normal distribution [6]. A normal distribution is defined as,

$$f(R) = \frac{1}{\sqrt{2\pi}\sigma} e^{-((R-\mu)^2/2\sigma^2)}, \quad \text{for } -\infty < R < +\infty \tag{2.1}$$

where μ and σ are respectively the mean and the standard deviation of the distribution. Electrical resistance can also show log-normal or inverse Gaussian behavior [2]. A log-normal distribution is given by [7]

$$f(R) = \begin{cases} 0, & \text{for } R \leq 0 \\ \dfrac{1}{\sqrt{2\pi}\sigma' R} e^{-((\ln R-\mu')^2/2\sigma'^2)}, & \text{for } R > 0 \end{cases} \tag{2.2}$$

where μ and σ are determined by

$$\mu = e^{\mu'+\sigma'^2/2} \tag{2.3}$$

$$\sigma^2 = e^{2\mu'+\sigma'^2}(e^{\sigma'^2} - 1). \tag{2.4}$$

An inverse Gaussian distribution is given by [2]

$$f(R) = \begin{cases} 0, & \text{for } R \leq 0 \\ \dfrac{\sqrt{\alpha}}{\sqrt{2\pi} R^{3/2}} e^{(\alpha(R-\mu)^2/2\mu^2 R)}, & \text{for } R > 0 \end{cases} \tag{2.5}$$

where $\sigma^2 = \mu^3/\alpha$ is the variance. When $\mu \gg \sigma$ and $R > 0$, log-normal and inverse Gaussian distributions can be reduced to a form similar to a normal distribution with a slight degree of skewness [2]. This can be seen in (2.6) and (2.7) respectively.

$$f(x) \approx \frac{1}{\sqrt{2\pi}\sigma(1 + x/\mu)} e^{-(x^2/2\sigma^2(1+x/\mu))} \tag{2.6}$$

$$f(x) \approx \frac{1}{\sqrt{2\pi}\sigma(1 + x/\mu)^{3/2}} e^{-(x^2/2\sigma^2(1+x/\mu))} \tag{2.7}$$

where the statistical variable $x \equiv R - \mu$.

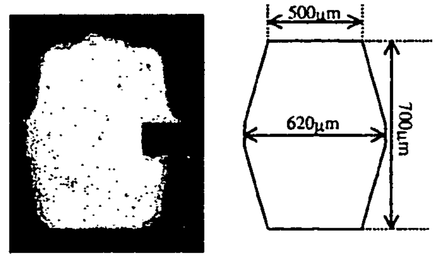

Fig. 1. Cross section of a conductive elastomer button with a schematic displaying the average dimensions.

B. Operating Reliability of a Device Employing a Group of Electric Contacts

For an electronic device employing n electrical contacts, the contact operating reliability p_D is given by

$$p_D = \prod_{i=1}^{n} p_i \tag{2.8}$$

where p_i ($i = 1, 2, \cdots, n$) is the operating reliability of each individual contact. For uniform contacts, each having an operating reliability p, (2.8) simplifies to

$$p_D = p^n \tag{2.9}$$

The operating reliability of each individual contact is based on the operational requirement of maximum electrical resistance R_0, i.e.

$$p = \int_0^{R_0} f(R)\, dR \tag{2.10}$$

Equation (2.10) shows that the operating reliability of an electric contact is a function of resistance requirements. For a contact, a high resistance requirement yields a high operating reliability. On the other hand, the operating reliability of an electric contact is also a function of contact loads. Within the operating range, a high contact load will increase the operating reliability, if time effects, such as wipe and wipe-associated corrosion, are assumed to be negligible.

III. Experimental Procedure

Contact resistance measurements were performed on conductive elastomer sockets manufactured by Thomas and Betts. Each socket consists of an array of electrically conductive elastomer buttons. The buttons are produced by a proprietary process that embeds metal particles in an elastomeric matrix. The material is then formed into small, barrel-shaped buttons (Fig. 1). The buttons are arranged in an array and attached to the socket frame using a thin, plastic sheet (Fig. 2).

The socket is designed to electrically connect land grid array (LGA) component I/Os with metallic traces on PCB's. When a mechanical load is applied and the elastomer contacts compress, the resulting reduction in volume allows the metal particles to form a percolative network and provide a path for electrical conduction. A magnified image of the conductive elastomer button array is shown in Fig. 3.

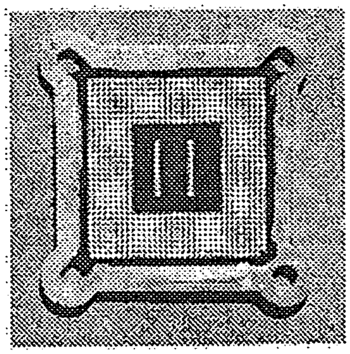

Fig. 2. Land grid array (LGA) elastomer socket with 787 I/Os.

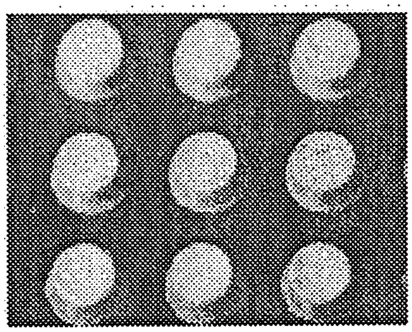

Fig. 3. Magnified electrically conductive elastomer button array. The button pitch is 1.27 mm.

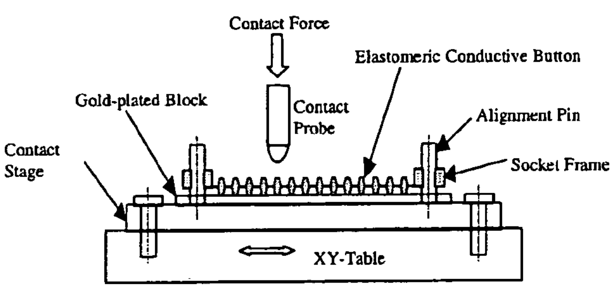

Fig. 4. Schematic of the experimental setup for contact resistance measurements using the ACRP.

Resistance measurements were conducted using an Automatic Contact Resistance Probe (ACRP) developed by the CALCE Electronic Products and Systems Center (Fig. 4). Details on the construction and operation of the ACRP have been reported previously [8]. In this study, the capability of automatic multi-point contact testing was built into the ACRP. This allows contact load and probe position to be computer controlled. To minimize resistance during measurements, a stainless steel block, plated with 30 mil gold over 100 mil nickel, was placed between the contact stage and the elastomer socket.

Three sockets, each with 787 contacts were tested. Electrical resistance was measured at 10 g intervals up to a maximum contact load of 60 g.[1] The measured electrical resistance R consists of the contact resistance between the probe and an elastomer button R_{cu}; the bulk resistance of the elastomer button R_b, the contact resistance between the contact stage and the elastomer button R_{cl}, and the circuit resistance R_{cir}:

[1]Sixty grams is considered the desired contract load during placement of a LGA component into the elastomer socket.

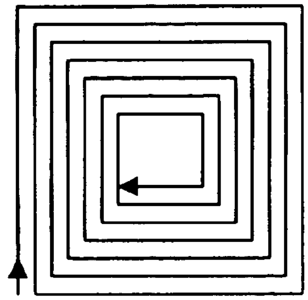

Fig. 5. Loop diagram used to measure fluctuations due to changes in circuit resistance.

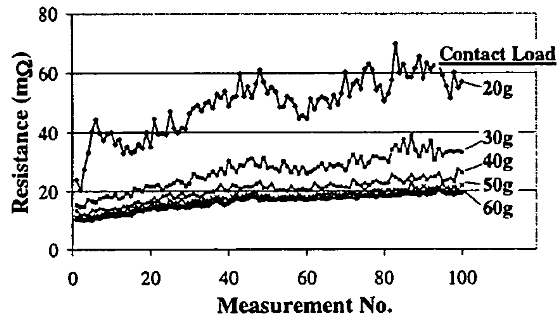

Fig. 6. Change in contact resistance over a period of 100 measurements on a single elastomer button as a function of contact load.

$$R = R_{cu} + R_{cl} + R_b + R_{cir}. \tag{3.1}$$

It is desirable to have the distribution behavior be primarily influenced by the intrinsic variability of the elastomer buttons. Variations from measurement-to-measurement and fluctuations in the circuit resistance can affect the distribution of contact resistance data and must be accounted. Measurement variabilities were quantified through multiple contact measurements of individual elastomer buttons. Within the electrical circuit used to measure contact resistance are connectors, where variability in their contact resistance could result in inaccurate determination of the distribution function. In addition, location effects due to possible inconsistencies in the surface quality of the gold-plated block could result in high resistance readings incompatible with the intrinsic variability of the elastomer buttons. To quantify the effect of resistance fluctuations in the circuit and disparities in the gold finish, the elastomer component socket was removed and 700 contact resistance measurements were performed on the gold-coated stainless steel block in a loop pattern (Fig. 5). These measurements assessed the mean and standard deviation of the circuit resistance, R_{cir}.

IV. Results

To determine resistance fluctuations due to measurement variability, 100 contact resistance measurements were performed on one elastomer button. The results, displayed in Fig. 6, show an increase in contact resistance with successive

TABLE I
MEAN (μ), STANDARD DEVIATION (σ), AND STANDARD DEVIATION-MEAN RATIO OF THE CONTACT RESISTANCE OF ELASTOMER BUTTONS, R_{CU}, AFTER A SERIES OF TEN MEASUREMENTS

		CONTACT LOAD					
		10g	20g	30g	40g	50g	60g
Button #1	μ	124.7	27.26	14.48	11.32	10.36	9.930
	σ	80.24	2.421	0.4830	0.3363	0.3527	0.3114
	σ/μ	0.6434	0.0888	0.0333	0.0297	0.0340	0.0314
Button #2	μ	128.2	34.23	17.80	13.44	11.74	10.77
	σ	80.55	3.384	1.019	0.2949	0.3509	0.2445
	σ/μ	0.6283	0.0988	0.0572	0.0219	0.0299	0.0227

Units are in milli-Ohms.

TABLE II
MEAN (μ), STANDARD DEVIATION (σ) AND STANDARD DEVIATION-MEAN RATIO OF THE CONTACT RESISTANCE OF ELASTOMER BUTTONS AS A FUNCTION OF CONTACT LOAD

	CONTACT LOAD					
	10g	20g	30g	40g	50g	60g
μ	176.5	34.36	22.12	16.26	12.07	9.88
σ	512.9	16.09	6.94	4.32	2.22	1.81
σ/μ	2.906	0.468	0.314	0.266	0.184	0.183

Units are in milli-Ohms.

loading. Multiple contact resistance measurements performed on other elastomer buttons verified that this progression in resistance values is an intrinsic wear-out mechanism of the elastomer button and not due to degradation of the measurement setup. While this behavior could be of some concern to end-users, it negates the effectiveness of using this technique to quantify measurement variability. To remove time-effects from measurement variability, ten contact resistance measurements were performed on two elastomer buttons. The mean circuit resistance, R_{cir}, is subtracted from the measured resistance in order to obtain the elastomer button contact resistance values displayed in Table I.

The mean circuit resistance, R_{cir}, was determined to be 19.01 mΩ and the standard deviation was 0.05 mΩ at 60 g contact load. A high contact load was used to avoid variability due to measurement.

The results of measuring the contact resistance of three sockets of 787 buttons is shown in Table II. The mean circuit resistance, R_{cir}, is subtracted from the measured resistance in order to obtain the elastomer button contact resistance values. Possible time-effects were avoided by performing contact resistance measurements only once on each button. Comparing the standard deviations from measurements (~0.3 mΩ at 60 g contact load), circuit resistance (0.05 mΩ), and total resistance (1.81 mΩ at 60 g contact load), we can see that the distribution of the total resistance is dominated by the intrinsic variability of the elastomer buttons. Measurement variability does play a small role in resistance distribution (approximately 10–15%). However, the ACRP was designed to mimic real-world loading conditions and the small effect of measurement can be accepted to simulate variability due to loading conditions.

Statistical parameters for the distribution functions were obtained from the experimental data. An example of the distribution functions can be seen Fig. 7, where the inverse Gaussian distributions are plotted as a function of contact load. To show the degree of fitting, the experimental data for the 60 g contact load is shown in conjunction with the curve generated by its distribution function. Note the increase in the skew and the width of the distribution curves with decreasing load.

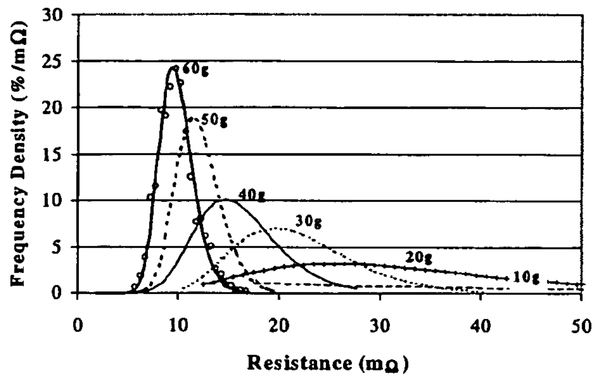

Fig. 7. Inverse Gaussian resistance distributions of electrically conductive elastomer buttons under various contact loads. The experimental data for 60 g contact load (open circle) is compared to the calculated distribution.

TABLE III
AVERAGE RELATIVE DEVIATION FROM MATHEMATICAL DISTRIBUTIONS

	CONTACT LOAD			
Distribution Type	30g	40g	50g	60g
Normal	5.761	3.639	3.271	3.041
Log-normal	3.706	2.439	2.278	1.653
Inverse Gaussian	3.626	2.395	2.257	1.648

The dependent variable, frequency density f_i, in the figures is defined by

$$f_i \equiv \frac{n_i}{n \Delta R_i} \tag{4.1}$$

where n_i is the observed frequency among the total n tested samples within the resistance interval $(R_i, R_i + \Delta R_i]$.

V. RELIABILITY ANALYSIS

The fitness of a distribution to a particular set of experimental data can be quantified by calculating an average relative deviation,

$$\xi \equiv \sqrt{\sum_i \frac{[f_i - f(R_i)]^2 \Delta R_i}{f(R_i)}}. \tag{4.2}$$

The obtained average relative deviations for the different distributions over a range of contact loads are listed in Table III.

Below 30 g contact load, the resistance distributions become asymmetric and highly skewed to large resistance values. Comparison of the standard deviations from Tables I and II show that this skewed behavior is primarily an intrinsic effect, though one might expect that measurement variation would dominate at these low loads. The three distributions used in this study are unable to define outlying resistance performance at 10 g and 20 g contact loads. Therefore, at these loads, it will be difficult for an operator to predict or control the reliability of this system.

TABLE IV
OPERATING RELIABILITY OF AN ELASTOMER BUTTON AND AN ELASTOMER SOCKET*

I/O #	CONTACT LOAD					
	10g	20g	30g	40g	50g	60g
Button Contact Reliability						
N/A	1.5247	11.358	48.746	80.962	99.921	99.999
Socket Operating Reliability						
256	0.0000	0.0000	0.0000	0.0000	81.662	99.770
787	0.0000	0.0000	0.0000	0.0000	53.646	99.294
1089	0.0000	0.0000	0.0000	0.0000	42.243	99.025

*: assuming an operational requirement of contact resistance less than 20mΩ

Over a range of contact loads 30 g to 60 g, the inverse Gaussian distribution provides a best fit to the experimental data. Using an inverse Gaussian distribution and a contact resistance requirement of $R \leq 20$ mΩ, the operating reliability of each individual elastomer contact was determined. From (2.9), we can calculate the operating reliability of the entire component socket (see Table IV). As an example, given an operating resistance requirement of 20 mΩ, a contact load of at least 60 g per contact is needed to maintain a socket operating reliability above 99%.

This methodology does allow for some flexibility, depending upon which parameter is mission critical. If appropriate for the application, a higher maximum resistance specification, such as 30 mΩ, will result in a higher operating reliability.

VI. CONCLUSIONS

In this paper, contact resistance measurements were performed on a component socket composed of elastomer button interconnects. Fluctuations in resistance data were shown to be a result of the intrinsic variability of the elastomer buttons. It is reasonable to think this true of all elastomer sockets although different types of elastomer interconnects may have different resistance variations. In order to predict outlying resistance behavior, this variability was fitted to three distribution functions: normal, log-normal, and inverse Gaussian. An inverse Gaussian distribution was found to provide a best fit to experimental data and was used to determine the operating reliability of individual elastomer interconnects as a function of contact load. The evaluation process was then extended to define the contact load necessary to achieve an operating reliability of 99% for an entire component socket, given a resistance specification. This methodology suggested an operating reliability assessment method of any electrical contacts and interconnects.

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